INVESTIGATION OF THE EFFECT OF MACRO-LAYERS OF AIR ON THE THERMAL INSULATION PROPERTIES OF CLOTHING ASSEMBLIES

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A person's clothing represents a composite sequence of layers made up of textile materials and air.

Air layers in clothing are termed microlayers (where material surfaces are in contact with each other, Fig. 1a.) and macrolayers (where material surfaces are not in contact with each other, Fig. 1b.).

As there is little published information on the actual thickness of air layers in clothing, or their effect on its heat protective qualities, a method[1] has been established to measure the thickness δ_B* of the air layers in certain sets of men's clothing.

It is established that, in practice, layers of air between the body and the underclothing, and between the underclothing and the shirt (Trans.note - literally the "outer underclothing") do not exist, because these garments despite their loose cut are pressed relatively closely to the body by the next successive layers of clothing, forming folds. At the same time in an overcoat, the thickness of the air layer between the outer coat and lining is significant, although an overcoat is cut less fully.

A suit's silhouette (straight , or patially loose fitting**), has an effect on the thickness of the air layer only at the waist, where δ_B is greater in the straight silhouette.

The magnitude δ_B is greater between layers of material in the same garment (e.g. between an outer part and its lining) than between separate items in the set of clothing (e.g. between the lining of the overcoat and the outside of the jacket).

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*In the symbol δ_B, $_B$ appears to represent BoЗAYX (Vozdukh), meaning 'air' -

** The inference here is a suit which is belted at the waist - Translator's notes.

The complexity of the surface of a person's body, the body movement and the varying degree of contact of different areas of clothing with the body lead to considerable irregularity in the positioning of the layers of air in clothing and changes in their thickness, which in practice can diminish to 0 (see Table). Therefore the thermal insulation created by air layers in ordinary clothing is not very effective.

However, as about 80% of the cost of manufactured garments lies in the raw materials, it is sensible to study the possibility of using air as thermal insulation in clothing, so as to economise in the use of warming materials.

The study
In ~~this work~~ the heat protective qualities of sets of clothing materials with their air layers were studied so as to select the optimum parameters of macrolayers of air acting as the thermal insulator in the clothing. The experiments took place in a flat (Trans. note - 'plane' is another literal translation) bicalorimeter PB-63[2]. Sets of clothing of air-dry materials with macrolayers of air between them were studied, and induced convection was absent.

Let us examine how the thermal resistance of an air layer depends upon its thickness.

The effective coefficient of thermal conductivity λ_{ef} of an air layer equals[3]:

$$\lambda_{ef} = \lambda_{cond} + \lambda_{rad} + \lambda_{conv} \qquad (1)$$

where λ_{cond}, λ_{rad}, λ_{conv} are the coefficients of thermal conductivity corresponding to conduction, radiation and convection in watts/m. degree. The convection transfer of heat in an air layer is determined by the criterion Gr.Pr, and when $Gr\,Pr < 1000$, for practical purposes it does not exist.

The thickness of air layers in men's clothing

Set No.	Designation of clothing	Composition of the set			$\delta_B \cdot 10^3$ m.
		Item	Materials	Layers	
1	Normal	Underclothing	Underwear material	Skin - underclothing	0
		Shirt	Flannel Pat: 1646	Underclothing - shirt	0
		Straight fitted jacket	Suiting cloth Pat: 23359	Shirt - jacket surface	0
			Lining serge	Jacket surface - lining	0 ÷ 7

Set No.	Designation of clothing	Composition of the set			$\delta_B \cdot 10^3$ m.
		Item	Materials	Layers	
2	Normal	Underclothing Shirt Partially loose fitted jacket	Underwear material Flannel Pat: 1646 Suiting cloth Pat: 23359 Lining serge	Skin - underclothing Underclothing - shirt Shirt - jacket surface Jacket surface - lining	0 0 0 0 ÷ 7
3	Mid-Season	Straight fitted overcoat Set 1	Thick woollen cloth Pat: 46253 Lining serge	Coat surface - lining Coat lining - jacket surface	0 ÷ 9 0 ÷ 5
4	Mid-Season	Straight fitted overcoat Set 2	Ditto	Ditto	0 ÷ 9 0 ÷ 6
5	Mid-Season	Partially loose fitted overcoat Set 1	Ditto	Ditto	0 ÷ 8 0 ÷ 4
6	Mid-Season	Partially loose fitted overcoat Set 2	Ditto	Ditto	0 ÷ 8 0 ÷ 8
7	Winter	Straight overcoat with quilted lining Set 1	Thick woollen cloth Pat: 46253 Quilt Pat: 4929 Lining serge	Ditto	0 ÷ 11 0 ÷ 4
8	Winter	Straight overcoat with quilted lining Set 2	Ditto	Ditto	0 ÷ 11 0 ÷ 6
9	Winter	Partially loose fitted overcoat with quilted lining Set 1	Ditto	Ditto	0 ÷ 10 0 ÷ 5
10	Winter	Partially loose fitted overcoat with quilted lining Set 2	Ditto	Ditto	0 ÷ 10 0 ÷ 8

Set No.	Designation of clothing	Composition of the set			$\delta_B \cdot 10^3$ m.
		Item	Materials	Layers	
11	Winter	Straight overcoat with an unquilted warm padding Set 1	Thick woollen cloth Pat: 4949 2 layers of rough wadding. Pat: 46	Outer coat - warming padding Warming padding - lining	$0 \div 6$ $0 \div 5$
12	Special clothing	Jacket with attaching warming padding	Miner's jacket Pat: 3289 Rough drill 3 layers of rough wadding	Outer jacket - warming padding	$0 \div 18$

This tabulation showed that when $\delta_B < 10 \cdot 10^{-3}$ m, transfer of heat by convection in an air layer can be ignored. Then

$$\lambda_{ef} = \lambda_{cond} + \lambda_{rad} \tag{2}$$

and

$$\frac{1}{R_{ef}} = \frac{1}{R_{cond}} + \frac{1}{R_{rad}} \tag{3}$$

when R_{ef}, R_{cond}, R_{rad} correspond to the effective, conduction and radiation thermal resistance, m^2 degrees/watt.

With a simple rearrangement we have

$$R_{ef} = \frac{R_{rad}}{1 + \lambda \frac{R_{rad}}{\delta_B}} \tag{4}$$

where λ is the coefficient of thermal conductivity of air , watts/m degree.

Let us examine R_{rad}

$$R_{rad} = \frac{\delta_B}{\lambda_{rad}} \tag{5}$$

$$\lambda_{rad} = 0.227\ \delta_B\ \varepsilon_{introduced} \left(\frac{T_{mean}}{100} \right)^3 \tag{6}$$

where $\varepsilon_{introduced}$ is the introduced coefficient of blackness* of radiation of the surfaces bounded by an air layer;

T_{mean} is the mean temperature of the air layer[3].

Then

$$R_{rad} = \frac{1}{0.227\ \varepsilon_{introduced} \left(\frac{T_{mean}}{100} \right)^3} \qquad (7)$$

From Formula (7) we see that with a decrease in ε for the surfaces bounded by an air layer, the radiation thermal resistance increases. Consequently the positioning of the air layer between materials with a low value of ε increases the effectiveness of the thermal insulation which it creates in the clothing.

However at the present time there is very little published data indeed on the coefficient of blackness of radiation of materials for clothing.

As it is known that the radiation of rough surfaces compared to smooth surfaces is distinguished by their greater degree of blackness[4], studies were carried out on the thermal resistance of the air layer bounded by materials with different surfaces; felt having pile or nap (lining fur), felt (thick woollen 'Miners" cloth Pat: 46216), smooth (lining serge) and metallized (metallized lining fabric).

It was established that when there is an increase in the thickness of the air layer from 0 to 8 mm, the thermal resistance rises sharply; subsequently a steady growth is observed. Experimental data differs insignificantly from the calculated data. The character of the surface of the materials studied has only a minor influence on R_{ef} (Fig. 2).

Thus an air layer of thickness 5-8 mm increases the thermal resistance of a set of clothing by 50-70%. Therefore it is a valid problem to design sets of warming clothing containing stable air layers.

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*YEPHOTA (Chernota) - lit. 'blackness'. I am unable to find a more scientific term for this - Translator.

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FIGURE CAPTIONS

Fig. 1. Sets of materials with microlayers (a) and macrolayers (b) of air.

1 - Material

2 - Air Layers.

Fig. 2. The relationship between the effective thermal resistance of an air layer and the thickness of the air layer in materials with surfaces of varying roughness.

a - thick woollen 'Miners' cloth Pat: 46216. b - lining fur.

c - lining serge. d - metallized lining fabric.

$R.m^2$ degrees/watt

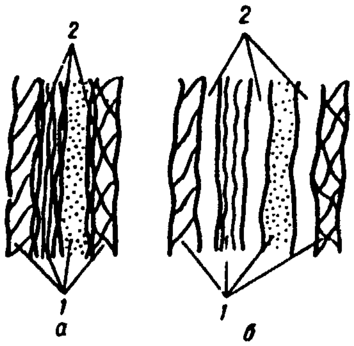

FIG 1

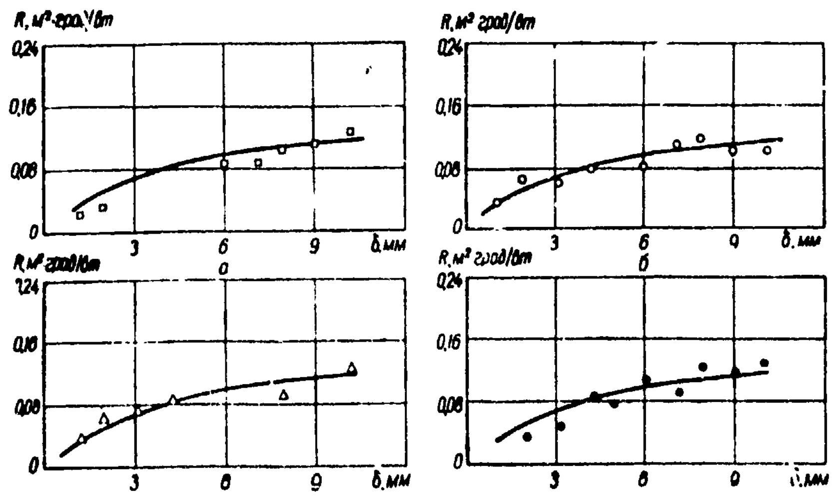

FIG 2